A SPACECRAFT GOING BEHIND THE SUN CAN SUPPORT SOHO

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ABSTRACT

A magneto-Doppler imager and X and Ka band radio communication system sent to the other side of the Sun can support the extended SOHO mission in several ways:

- Soon after launch the spacecraft can observe weak photospheric fields simultaneously with SOHO/MDI and ground instruments. Combining these data sets gives information on the inclination of the fields. Changes in inclination gives evidence of magnetic shear buildup, perhaps leading to CMEs.
- When spacertaft is off the Sun's limb (as seen from S0110) it measures photospheric magnetic and velocity fields beneath CMEs observed by LASCO. It searches for emerging magnetic flux contributing to CME destabilization.
- When spaceraft is approaching solar occultation, the Faraday rotation of the radio signal passing through the corona is measured. The coronal magnetic field can then derived from the Faraday rotation and electron density. Thus the magnetic field in the corona observed by I, ASCO/Etrl' is measured. Using Ka band, Faraday rotation can be measured in the previously unexplored regions of the inner corona, 1.1 – $4R_{\odot}$.

Key words: photospheric and coronal magnetic fields; CMEs

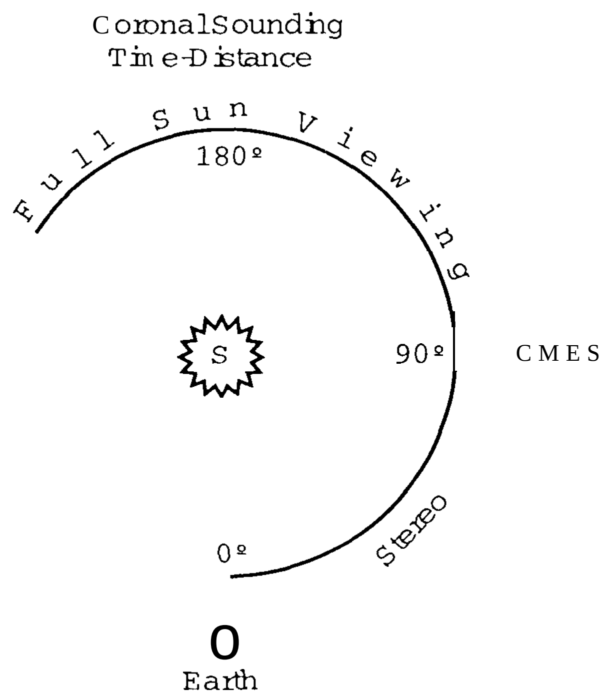

Figure 1. As the Earth-Sun-spacecraft angle increases *new observation opportunities open.*

1. WHY GO AROUND AND BEHIND THE SUN?

Solar variations, including active regions, flares, coronal mass ejections and solar wind, originate in magnetic fields. Magnetic fields are generated in the solar convection zone, emerge at the photosphere and govern the structure of the corona. Magnetic energy is believed to be converted into heat and mass motions driving the solar wind. This knowledge comes from observations made from the ground and near-Earth spacecraft Views of the Sun from other angles are needed, however, to better understand how magnetic fields are generated and cause solar variability.

Why not just wait until the rotating Sun brings a structure into view? This would be possible if structures do not change as they rotate. However, solar magnetic fields do change. These changes take place on all time scales. "1'here are slow changes, for example the 11-year solar cycle, and rapid changes at small scales, such as solar flares. Phenomena on troth these time scales are effectively studied from Earth alone. There are, however, largescale magnetic structures on the solar surface that change on time scales less than or comparable to the solar rotation period. These changes are transferred to the corona rapidly (at the Alfvén speed). Coronal structures such as helmet streamers or coronal holes typically change on time scales of days or weeks.

Thus observations from Earth alone are insufficient to study many important phenomena, A mission to go around and behind is designed to fill this need. We call it MagSonas (Magnetic Structures on and around the Sun). It enables observations from behind the Sun and on the way to this position (Fig. l). When behind the Sun the spacecraft will sound magnetic fields in the inner corona.

In this paper we discuss some scientific problems that can be solved using simultaneous observations from S0110 and MagSonas.

2. A UNIQUE OPPORTUNITY TO LOOK INSIDE THE SUN

The solar dynamo is maintained by motions of electrically-conducting plasma in the convection zone, the outer 1/3 of the radius of the Sun Parker 1978; Zeldovich et al. 1983. Theoretical studies, confirmed by several helioseismology experiments, strongly suggest that the solar cycle dynamo is located in a shear layer (tachocline) just below the base of the convection zone (e.g. Kosovichev et al. 1997). However, the structure of the dynamo region and the strength and time-behavior of the fields that produce activity on the Sun are poorly known

Simultaneous measurements of the oscillations of the photosphere from Earthside (SOHO/MDI) and the back side of the Sun (MagSonas) will enable unique helioseismic imaging of the Sun's interior. (This idea is put forfard by J. Harvey.) These images can map the interior structure and dynamics with resolution that is unavailable using observations from a single perspective. This unique opportunity utilizes the time-distance helioseismolog technique Duvall et al. 1993. Among the outstanding questions that could be addressed are the degree to which the deep stratification of the Sun is radially symmetric or is lumpy. It might also be possible to detect fine structure at the base of the convection zone such as localized jets or magnetic-field-aligned temperature perturbations postulated to be associated with solar activity.

The new technique yields the time for an acoustic wave to travel from a point at the surface to a distant point and vice versa. Combinations of many different points, wave periods and wavelengths are used to build up images of the sound speed and mass motions throughout the interior. Until this opportunity, the technique has been limited to fairly shallow diagnosis and has not added much to our knowledge about the solar-cycle-gerleratirlg dynamo region at the base of the convection zone or the energy-generating core, both regions crucial for understanding basic solar physics. With MagSonas, high-frequency waves, which pass only once through the solar interior and provide the highest spatial resolution, can be observed at the antipode of the Earth-Sun line and across the earthside of the Sun. This combination allows deep imaging of the interior not available by any other known technique.

3. EMERGING FIELDS AND ACTIVITY COMPLEXES

The magnetic flux that emerges and forms active regions shows a remarkable tendency to cluster on the solar surface (Gaizauskas et al. 1983). New bipoles preferentially emerge in regions where flux has previously emerged; sunspots occur in groups; sunspot groups occur within activity centers, and these activity centers in turn cluster among themselves Harvey & Zwaan 1993. Parker (1984) pointed out that clustering of solar activity constrains possible mechanisms of magnetic field generation (dynamos) and gives essential information concerning the dynamics of solar convection.

Typical lifetimes of individual complexes identified to elate are from one to seven rotations. However, important evolutionary changes within complexes take place on time scales of many days to weeks. During this time activity complexes give rise to solar flares and coronal masse ejections which may cause energetic solar particle events and major geomagnetic storms. For example, in March 1989 inactivity complex produced CMEs, an energetic solar particle event and the most intense geomagnetic storm seen in 120 years Allen et al. 1989. The activity complex built to a maximum while it was on the far side of the Sun.

With the present handicap of single-hemisphere observations only statistical studies of complexes arc possible. Near solar minimum individual activity complexes can usually be identified and their evolution is slow. Near solar maximum, there is rapidly evolving magnetic activity and complexes are much changed when they reappear from over the limb (Fig. 2).

Only by observing both sides of the Sun can we have sufficient continuity to follow the evolution of individual activity complexes, With extended observations the complexes can be satisfactorily followed and their evolution studied. For the first time our observations at solar maximum will be continuous enough to study the evolution of individual complexes and to find out when, where and how much flux emerges during an activity complex life-time,

4. BUILDUP AND ACCELERATION OF CORONAL MASS EJECTIONS

4.1. Stereo Observations of Magnetic Fields in CMEs Buildup Area.s

Solar events have important consequences on Earth. Coronal Mass Ejections (CMEs) and/or solar flares produce high energy particle events and geomagnetic storms that threaten spacecraft systems and

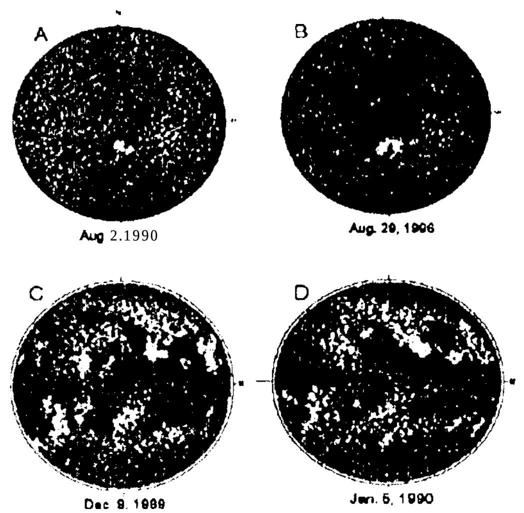

Figure 2. Extending viewing of the Sun is required in order to study the evolution of activity at solar maximum. Returning activity complexes evolve slowly at solar minimum (A, B) and rapidly at maximum (C, D) (Mount Wilson magnetograms). Field out of (into) the Sun is white (black).

power grids. Magnetic fields play a crucial role in the buildup and acceleration of CMEs (Hundhausen 1997). At the same time conclusions about these fields in the corona are now drawn on the assumption that coronal features observed in white light or X-rays trace out magnetic lines.

These Sun-Earth connections have been studied since 1859 (Carrington, Hodgson). Since first directly observed by Skylab (Gosling et al. 1974), thousands of CMEs have been seen and hundreds of studies carried out. Especially impressive observations are now being made by SOHO/LASCO chronographs (Brueckner et al. 1 995), and Yohkoh X-ray imaging (Tsuneta et al. 1992). They show changes in the coronal fields on all t ime scales and CMEs that stretch from one side of the Sun to the other.

In spite of the many years of study, the causes of CMEs are still not understood. Although it is now generally believed that CMEs are related to the destabilization and eruption of the coronal magnetic structure overlying prominences and/or active regions, the mechanisms of this destabilization remain a mystery. Current popular concepts of the destabilization include energy buildup by shearing of magnetic fields through footpoint motion (Antiochos et al. 1994), and/or the addition of newly emerging magnetic flux in or near the region below closed coronal arcades (Feynman & Martin 1995). Recently the importance of magnetic field line topology has been stressed (Rust 1994; Gosling et al. 1995).

Measurements of the direction of the magnetic fields are required to study the topology of the magnetic fields and the development of shear. Earth based vector magnetographs can measure only strong fields near sunspots. However, the structures that erupt in CMEs are widely believed to be rooted in largescale photospheric fields that arc too weak ($\leq$ 100" G) to be detected by vect or magnetographs. Post-CME coronal structures have been inferred from YOHKOH soft X-ray images, but the build-up stage of CMEs can not be directly observed in soft X-rays. Pre-CME shearing and magnetic structure have not been inferred from soft X-ray images because the parts of the corona that erupt as a CME are not hot enough to emit X-rays until they have become destabilized.

Magsonas, by pleasuring the photospheric fields from a second angle simultaneously with earthside instruments will yield stereo observations of the line of sight intensity of these weak magnetic fields. Two components of the magnetic field vector and plasma flow can be obtained by combining these observations. The fields associated with the buildup to CM E can be observed for up to 10 consecutive clays. Increasing shear will be indicated by changing field inclination. The resultant CME can be observed by SOHO/LASCO on the solar limb. The changing inclination of these weak fields can be observed in no other way.

Newly emerging magnetic flux also is believed to contribute to the buildup of CMEs. Flux emergence often begins several days before quiescent solar filaments disappear (Feynman & Martin 1995). The disappearance is interpreted] as CME initiation. However, to check this interpretation we need to observe the flux emergence and the actual CME. The problem is that CMEs arc best observed when they occur near the limb while emerging flux is best observed far from the limb.

The Magsonas mission can solve this problem. When Magsonas is off the limb it will observe emerging flux beneath the CMEs seen by SOHO/LASCO. The Yohkoh X-ray imager will identify low coronal structures heated when the CME is initiated.

4.2. Derivation of CMEs' Magnetic Fields in the Corona

After initiation, CMEs are readily observed as density structures traveling through the corona, However, the magnetic fields within CME's, so essential to their dynamics in the corona (Hundhausen 1997) remain largely unmeasured. There are very few techniques that can detect magnetic fields within the corona. Even the newly proposed infrared solar telescopes can measure only intense fields close to the solar surface, not in CMEs. However, the fields inside a few CMEs have been estimated using Faraday rotation of polarized radio waves passing through the corona from the far side of the Sun (Bird et al. 1985). We will use and improve on this technique.

The Magsonas radio system is designed to serve a dual purpose, spacecraft communications and sounding coronal magnetic fields. It carries a linearly polarized Ka band transmitter and an X band transmitter and receiver. These snort wavelength bands will sound the corona at smaller distances from the Sun than ever before (i4 Rs).

Radio sounding gives integrated line of sight measurements. The deconvolution of this data has been problematic (Woo 1997). We will use an improved deconvolut ion met hod based on coronal modeling (Mikic & Linker 1996) using full Sun photospheric magnetic

Figure 3. *Projection of MagSonas trajectory on the solar corona superimposed on LASCO C2* images. *The Faraday rotation at these* lines will *be measured to* derive *the coronal* magnetic *field.*

field measurements enabled by Magsonas. Combined with improved coronal models Magsonas radio soundings will reveal the magnetic fields within the inner corona ($\leq$ 10 Rs) and within CMEs.

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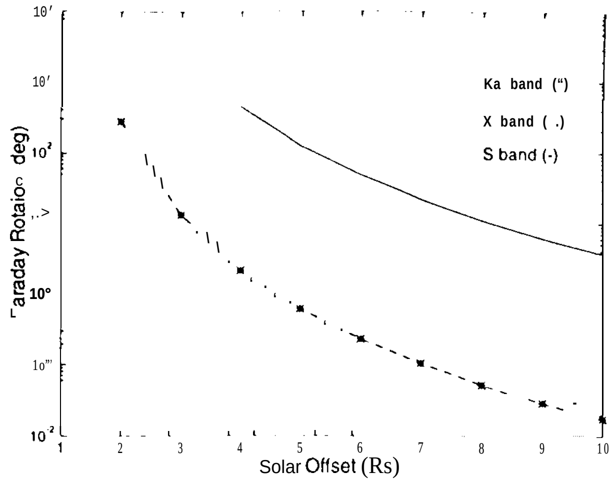

Figure 4. *To allow the radio* sounding *of the* inner corona *two* frequencies *(X-band and Ka-band)* will *be used. The* radio signal *from the spacecraft will be* linearly *polarized to* measure *the Faraday rotation. Schematic of Faraday rotation jor a scan oj a magnetic loop* is *shown.*

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